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THE EFFECTS OF HEAT AND ULTRA-VIOLET LIGHT ON THE RECTIFYING ACTION OF SOME CRYSTALS.

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ABSTRACT. The effects of heat and ultra-violet light on the rectifying properties of some crystals have been experimentally investigated. The rectifying property is observed generally to decrease with the rise of temperature, as has also been observed by previous observers. In the case of the iron pyrites crystal, which has been studied in detail, two types of rectifying points have been found. In the case of the first type the diminution in rectification with increase of temperature is due to a greater rate of increase in conductivity in the high-resistance direction than in the low resistance direction, while in the case of the second type it is due to an increase in conductivity in the high-resistance direction and a decrease in the low-resistance direction. It has also been observed that though the rectification tends to vanish in the case of iron pyrites at a temperature of 270°C., good rectifying points are found by trial on the surface of the crystal even at this high temperature contrary to the results reported by Khastgir and Das Gupta, according to whom the rectification disappears completely at 100°C.

The effect of ultra-violet light on the rectification is very feeble, in some cases the rectification increases and in other cases it diminishes.

§ 1. INTRODUCTION.

On account of the rapid development of the thermionic valve the use of the crystal-rectifier, one of the most sensitive detectors, has almost been forgotten. It has at present become practically obsolete in commercial application due also to the instability in its workings. The thermionic tube has so much attracted the attention of investigators that comparatively very little work has been done on crystals. Sufficient data have not therefore accumulated for the thorough understanding of the mechanism of rectification by these detectors. Several theories have, however, been put forward but none of them has as yet been completely satisfactory. We require more and more data for a complete grasp of the mechanism by which the asymmetric conduction is brought about in these rectifying systems; and it is the object of the present investigation to collect experimental facts which may, in future, be of some use in advancing a more complete theory of crystal rectification. A detailed study of the subject is also in progress in this laboratory and it is hoped that some of the results will be published soon.

It was found by Flowers,[1] that on heating a crystal of galena, its rectifying action diminishes with the increase of temperature and disappears altogether at about 270°C. On cooling, the rectification is partially regained. He also observed that parts of the crystal which carried no current were unaffected by heat.

A decrease in the rectifying property of several crystals was also noticed by Jackson[2] when he exposed them to ultra-violet light and X-rays. During the progress of the present work a paper by Khastgir and Das Gupta[3] was published in which has been recorded similar diminution in rectification of five different crystals. Further, these investigators have noted a complete disappearance of rectification by iron-pyrites when the temperature was raised to 100°C. The experiments of the present author with a few crystals have, however, always shown a definite decrease in the rectifying action on heating up to about 200° C, but never a complete disappearance of the property. Since the publication of the work by Khastgir and Das Gupta the experiments have been repeated with iron-pyrites several times. These repetitions have confirmed the former results which are given in this paper. The effect of ultra-violet light on crystal rectification has also been studied following, in some cases, Jackson's method and some of the results obtained are recorded here. It seems too early to attempt any theory of the effects observed during these investigations.

§ 2. EXPERIMENTAL.

A test tube about 4 cms. in diameter, fitted with a cork having four holes in it, was taken. Through one of the holes passed a copper rod carrying at its lower bent end a metal cup of an ordinary commercial crystal receiver. Through the central hole passed a glass tube in which could slide another narrower glass tube carrying the metal whisker in it. A steel whisker was used and the contact of the whisker with the outside circuit was made through a little mercury placed in a short piece of wider glass tube surrounding the one fitted into the central hole as shown in Figure 1. This ensured the pressure at the contact point being kept constant all throughout the experiment. Through the third hole passed a thermometer and the fourth one was left open. The test tube with all its fittings was placed in an electric heater provided with a rheostat by which the temperature could be regulated. A 1000-cycle audio-frequency oscillator was used as the source of alternating current when required and a sensitive galvanometer to measure the current. For the study of the effect of ultra-violet rays a quartz mercury-vapour lamp was used as the source of the light. The crystal was mounted as described above and the whole arrangement without the test-tube jacket was fixed at a small distance in front of the lamp so that the light from it could fall directly on the crystal contact. The rise of temperature in the neighbourhood of the crystal was about two to three degrees.

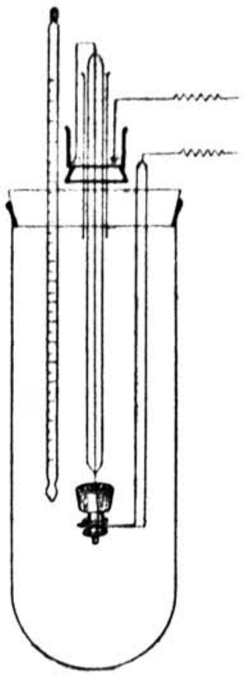

FIGURE 1.

§ 3. RESULTS AND DISCUSSIONS.

(a) *Effect of Heat.*

Iron-pyrites :

This crystal gives rectified currents in both directions of which the current from crystal to whisker is rather unsteady and that from whisker to crystal is prominent and steady. Again, there appear to exist two types of rectifying points. For one class, when the crystal is heated, the diminution in the asymmetric conductivity of the crystal contact is brought about by a greater rate of increase in conductivity in the high-resistance direction than in the low-resistance direction. For the other class the decrease in rectification is due to the diminution in conductivity in the low-resistance direction and the increase in conductivity in the opposite direction. This appears rather unusual and it will be too rash to arrive at definite conclusions with regard to this point without further investigation. Table I and Figures 2 and 3 show the effects

Iron-pyrites-steel.

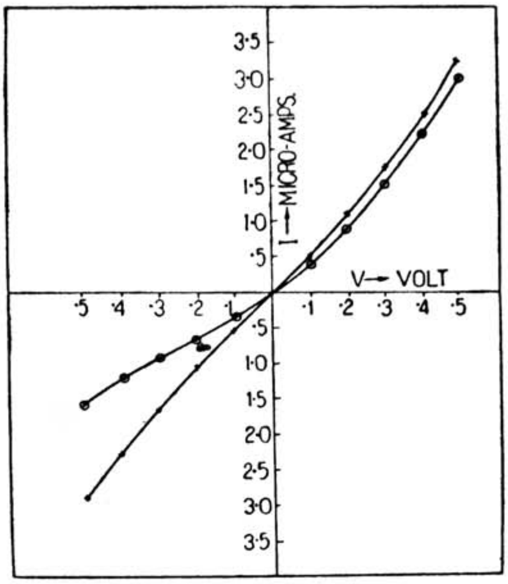

FIGURE 2.—Characteristic curves for first type of points.
o—o—o—o I-V curve at room temp. ×—×—×—× I-V curve at 195°C.

Iron-pyrites-steel.

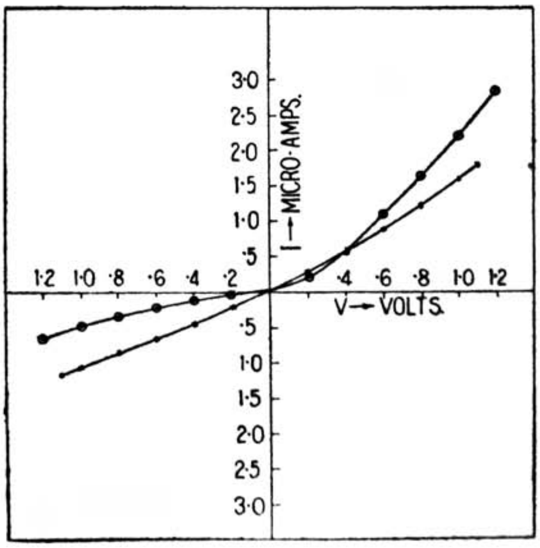

FIGURE 3.—Characteristic curves for second type of points.
o—o—o—o I-V curve at room temp. ×—×—×—× I-V curve at 205°C

of these two types of points. In each case the rectification diminishes with the increase of temperature; but it has never been found to vanish altogether up to a temperature of about 200°C. This has been verified by passing the alternating current from the 1000-cycle audio-frequency oscillator. The data

TABLE I.

Effect of heat.

	Voltage (Volts).	Current at room temp. (Micro amps.).		Current at higher temp. (Micro amps). Temp. = 195°C.	
		Crystal to whisker.	Whisker to crystal.	Crystal to whisker.	Whisker to crystal.
First type	0·1	0·32	0·41	0·54	0·58
	0·2	0·68	0·90	1·05	1·11
	0·3	0·93	1·51	1·70	1·77
	0·4	1·23	2·21	2·28	2·41
	0·5	1·60	4·03	2·89	3·25
	0·6	1·95	3·93	...	...
					Temp = 205°C.
Second type	0·2	0·06	0·20	0·18	0·23
	0·4	0·14	0·60	0·48	0·53
	0·6	0·22	1·11	0·67	0·88
	0·8	0·32	1·60	0·87	1·19
	1·0	0·48	2·18	1·09	1·56
	1·1	...	...	1·16	1·77
	1·2	0·66	2·84	...	...

given in Tables II and III and curves in Figures 4 and 5 show that for temperatures above 230°C. there is a rapid change in the rectified current and when the temperature goes above 270°C. the rectification tends to vanish. Good rectifying points have, however, been found by trial on the crystal surface even when the temperature was raised to 270°C. For comparison the characteristic curve for such a point at 270°C. is given in figure 6 along with the one for a fairly sensitive point at room temperature. The experimental data are entered in Table IV.

Iron-pyrites.

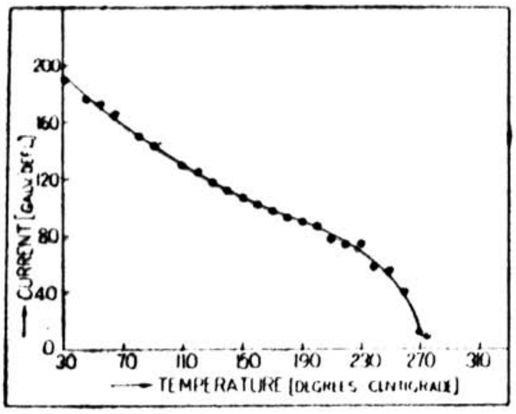

FIGURE 4. Variation of rectified current with temperature.

Iron-pyrites.

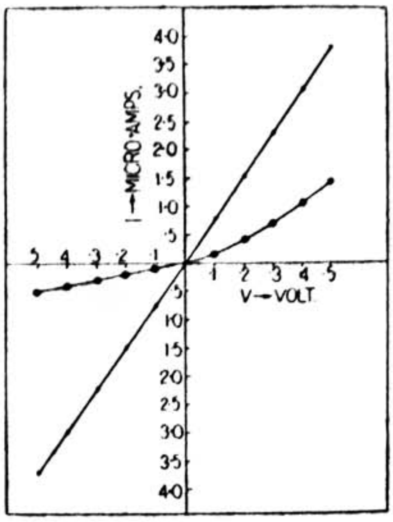

FIGURE 5. Effect of heat
o—o—o—o I-V curve at room temp.
×—×—× „ „ „ 270°C.

TABLE II.

Temperature variation of rectified current.

Temp. °C	Rectified current (Galv. defl.)	Temp. °C.	Rectified current (Galv. defl.).
30	190 divs.	170	96 divs.
45	177 „	180	92 „
55	173 „	190	89 „
65	165 „	200	85 „
80	150 „	210	77 „
90	144 „	220	73 „
110	130 „	230	72 „
120	125 „	240	57 „
130	116 „	250	54 „
140	110 „	260	39 „
150	105 „	270	10 „
160	100 „	274	8 „

Iron-pyrites.

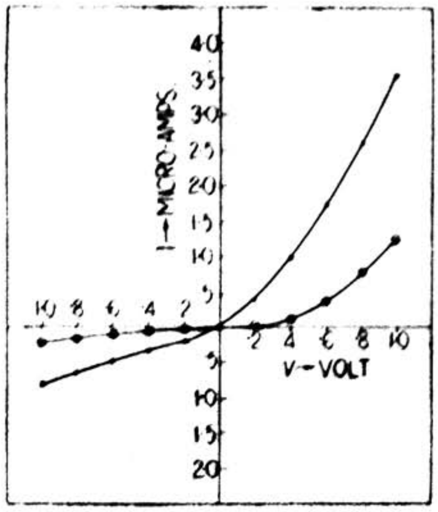

FIGURE 6.

o—o—o—o I-V curve for one of the best rectifying points at room temp.
×—×—× ,, ,, ,, ,, ,, ,, ,, at 270°C.

A crystal-crystal contact of iron-pyrites has also been tried. The rectifying action has been found to be comparatively small and the change in rectification on heating has also been small. In this connection it has been noted that if the

TABLE III.

Voltage (Volt).	Current at room temp. (Micro amps.)		Current at higher temp (Micro amps.) Temp. = 270°C.	
	Crystal to whisker.	Whisker to crystal.	Crystal to whisker.	Whisker to crystal.
0·1	0·10	0·15	0·77	0·78
0·2	0·20	0·37	1·50	1·55
0·3	0·31	0·68	2·25	2·28
0·4	0·41	1·05	2·98	3·06
0·5	0·51	1·45	3·72	3·83

TABLE IV.

Voltage (Volt).	Current at room temp. (Micro amps.)		Current at higher temp, (Micro amps.) Temp. 270° C.	
	Crystal to whisker.	Whisker to crystal.	Crystal to whisker.	Whisker to crystal.
0·2	0·03	0·03	0·20	0·37
0·4	0·09	0·10	0·34	0·95
0·6	0·12	0·37	0·51	1·75
0·8	0·17	0·78	0·65	2·60
1·0	0·22	1·24	0·78	3·54

currents in the two directions be determined for very low applied voltages then on heating the direction of the greater current changes for voltages above about 0·35 volt, so that while in the cold state the rectification ratio goes on increasing with the increase of applied voltage, at higher temperatures this factor

TABLE V.

Voltage (Volt.)	Current at room temp. (Micro amps.)		Rectification ratio.	Current at higher temp. (Micro amps.) [Temp. = 135° C.]		Rect. ratio.
	Up	Down		Up	Down	
0·04	0·39	0·40	0·025	0·73	0·60	−0·18
0·10	0·92	0·97	0·051	1·70	1·58	−0·07
0·15	1·39	1·50	0·073	2·50	2·40	−0·04
0·20	1·75	1·90	0·080	3·11	3·03	−0·03
0·25	2·21	2·47	0·105	3·89	3·84	−0·01
0·30	2·62	2·96	0·114	4·52	4·51	−0·002
0·35	—	—	—	3·32	5·32	0
0·40	—	—	—	5·92	5·97	0·008

TABLE VI.

Effect of heat.

Voltage (Volts).	Current at room temp. (Micro amps.)		Current at higher temp (Micro amps.)		
	Crystal to whisker.	Whisker to crystal	Crystal to whisker.	Whisker to crystal.	Temp.
Pyrolusite.					
0·2	0·05	0·05	0·41	0·41	
0·4	0·15	0·14	0·90	0·85	110°C
0·6	0·34	0·29	1·60	1·45	
0·8	0·60	0·48	2·55	2·30	
1·0	0·97	0·73	3·54	3·11	
1·2	1·53	1·11	—	—	
Master Crystal.					
0·2	0·19	0·05	0·51	0·46	
0·4	0·53	0·15	0·97	0·92	205°C.
0·6	0·90	0·29	1·45	1·38	
0·8	1·28	0·46	1·92	1·84	
1·0	1·70	0·65	2·38	2·30	

diminishes till a pressure of about 35 volt is reached when it becomes zero and then goes on increasing with the further increase of voltage. The results obtained are presented in Table V.

Pyrolusite and Master Crystal.

Both pyrolusite and the crystal known by the trade name Master Crystal give prominent rectified currents from crystal to whisker. The rectified current in the opposite direction has also been observed but in its strength is much smaller. On heating upto 205°C. there is a large diminution in the rectifying action of Master Crystal. The experimental results are given in Table VI and the characteristic curves in Figures 7 and 8.

Several other crystals, *e.g.* galena, copper-pyrites and zincite have also been studied, the results of which have not been entered here.

Master Crystal.

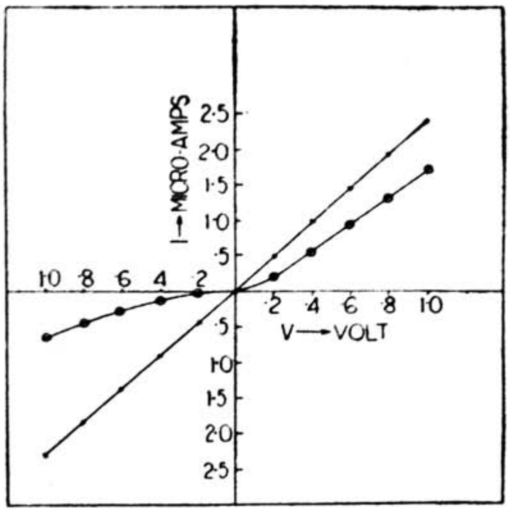

FIGURE 7.
Effect of heat.

o—o—o—o I-V curve at room temp.
×—×—× ,, ,, at 205°C.

Pyrolusite.

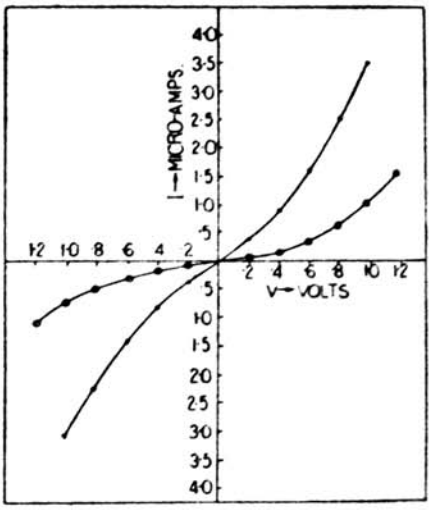

FIGURE 8.
Effect of heat.

o—o—o I-V curve at room temp.
×—×— ,, ,, 110°C.

(b) *Effect of Ultra-violet Light.*

For some crystals the direct determination of the variation of the rectified current has been made by passing the alternating current from the audio-frequency oscillator. The change in the value of the steady current in any one direction under a given applied voltage has also been studied simultaneously. For other crystals again characteristic curves under different conditions, *e.g.*, (1) before exposure, (2) under exposure, and (3) after the light has been cut off have been determined. The data obtained show that though there is a small increase in conductivity in the cases of all the crystals studied, the rectification has remained practically unchanged in some of the crystals while in others there has been an extremely small change. Some of the typical results are given in Tables VII and VIII and Figure 9. It has been noticed that the maximum increase in conductivity in some cases occurs in a very short time. On examining the characteristic curves for Master Crystal it appears that the rectification improves very slightly on exposure to ultra-violet light and this state persists for a long time even after the light has been cut off. As this crystal has exhibited certain interesting properties during these investigations it is proposed to continue the study of its rectifying action under ultra-violet light and X-rays.

Master Crystal.

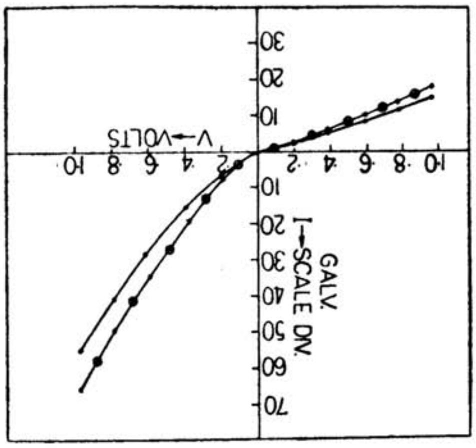

FIGURE 9.
Effect of ultra-violet light.
o—o—o—o I-V curve before exposure
×—×—× ,, ,, under ,,
o—o—o—o ,, ,, one hour after the light is off.

In conclusion, the author's thanks are due to Mr. N. Ray of the Department of Chemistry for kindly supplying some crystals and also to the author's colleagues of the Physics Department for their keen interest in the work.

TABLE VII.

Effect of ultra-violet light.

Time. (Mins.)	Currents (Galv. defl.)		Rectified current (Galv. defl.)	Temp.
	Crystal to whisker.	Whisker to crystal.		
FeS_2—Steel.				
0	52	130	153	29°C.
15	54	131	...	31·5°C.
25	54	131	...	...
35	54	132	152	...
45	55	134	...	...
60	55	134	151	32°C.
FeS_2—FeS_2.				
0	...	...	42·0	30°C.
10	...	...	42·0	...
25	...	...	42·0	...
35	...	...	41·5	...
40	...	...	41·5	32°C.

TABLE VIII.

Master Crystal.

Voltage (Volt.)	Current.					
	Before exposure. (Galv. defl.)		Under exposure. (Galv. defl.)		Light off. (Galv. defl.)	
	Crystal to whisker.	Whisker to crystal.	Crystal to whisker.	Whisker to crystal.	Crystal to whisker.	Whisker to crystal.
0·1	...	...	...	...	2·5	1·5
0·2	6	2·5	8	3	...	...
0·3	...	...	...	...	13	4
0·4	16	5·0	20	6	...	...
0·5	...	...	...	...	27	8
0·6	20	9·0	35	10	...	...
0·7	...	...	...	...	42	11·5
0·8	41	12·0	50	14	...	...
0·9	...	...	...	...	58	15·5
1·0	55	15·0	66·5	17·5	...	...

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